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APPLICATION FOR LETTERS PATENT

Low Distortion Audio Equalizer

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TECHNICAL FIELD

The present disclosure generally relates to an equalizer, and more particularly but not exclusively to adjusting an equalizer gain.

BACKGROUND

Computer hosted audio players are often implemented as a component of a streaming media system, and generally include an equalizer.

An audio player equalizer allows a user to control the frequency response of a digital audio signal. A user selects the frequency response of the audio signal by individually selecting the amplitude (or gain) of a number of different frequency bands. The gain of each band is generated by a digital filter application. To control the equalizer, the user selects a desired gain for each band through a computer input device. The gain for each band is generated by an equalizer application responding to the user selected gain.

An increase in selected gain in at least one band may saturate the audio signal and thus introduce distortion into the output audio signal. Distortion may be introduced by increased power in the audio signal if the audio signal amplitude is in a non-linear region of the amplification circuitry. Distortion may also be introduced by clipping, a phenomenon in which the amplitude of the audio signal exceeds the bounds of its digital representation. Clipping adds distortion and pop to the transduced sound of the audio signal. The traditional solution to this problem is a preamplifier that lowers the power of the audio so that the equalizer cannot add enough power to cause clipping. This kind of preamplifier introduces aliasing, thus reducing the accuracy of the audio data. That is undesirable. Another traditional solution to this problem is to detect that clipping is occurring, and then to normalize the audio signal so that it represents lower power. That is

also undesirable because that uses a large audio buffer to detect clipping over time, and has a latency (or response time) in detecting the distorted audio signal, thus introducing inaccuracy into the output audio signal.

SUMMARY

Briefly and not exclusively, systems, methods, and articles are described for lowering the gain of the first bands of an equalizer. The gain of the first bands of the equalizer are lowered in response to a user adjusted raised gain in the second band of the equalizer. The system includes a gain calculator to determine the lowered first band gains. In one implementation, the gain calculator is configured to determine the lowered first band gains so that the overall power represented by the equalizer audio output signal does not increase. In one implementation, the gain calculator is configured to determine the lowered first band gains so that the overall volume represented by the equalizer audio output signal increases a fraction of the increased volume caused by the raised second band gain.

In one exemplary implementation, one or more computer readable media store instructions that, when executed by at least one processor, cause the processor to perform acts that include computing a lower gain for at least one band of a multi-band equalizer in response to a user input to raise gain in one other band of the equalizer.

BRIEF DESCRIPTION OF THE DRAWINGS

The detailed description is described with reference to the accompanying figures..

Fig. **1** is a schematic of an exemplary embodiment of an audio system having a gain calculator to calculate equalizer gain settings.

FIG. **2** is a schematic of an exemplary audio system implemented on a computer system.

Fig. **3** is a schematic of an exemplary embodiment of an audio system having a gain calculator to calculate equalizer gain setting.

Fig. **4** is a schematic of an exemplary embodiment of an audio system having a gain calculator to calculate equalizer gain setting wherein an exemplary gain calculator algorithm is portrayed.

Fig. **5** is a schematic of an exemplary embodiment of an audio system having a gain calculator to calculate equalizer gain setting wherein an exemplary gain calculator algorithm is portrayed.

Fig. **6** is a flowchart of an exemplary method of calculating the gains of an equalizer.

DETAILED DESCRIPTION

A structure and a method to adjust the gain settings of a computer implemented multi-band graphic equalizer are described. In this description, reference is made to the accompanying drawings which form a part hereof, and in which is shown, by way of illustration, specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural or logical changes may be made without departing from the scope of the present invention. The following detailed description, therefore, is not to be taken in a limiting sense, and the scope of the present invention is defined by the appended claims.

FIG. **1** shows a pictorial representation of a computer hosted audio system **100**. The audio system **100** includes a computer user interface system **110** to provide for each band of an equalizer **120** a user selected gain setting to a gain calculator application **130**.

The computer user interface system **110** comprises a computer user interface **140** and a computer interface application **150**. The computer interface **140** provides a man-machine interface so that a user may input user selected gain settings (or changes in gain settings) for each band of the multi-band equalizer **110**. The computer interface **140** is illustratively portrayed here as a computer monitor. The computer monitor is configured to display a structure for user selection of gain (or change in gain) for each band of the equalizer **110**. One implementation of the computer interface **140** is as a structure comprising multiple simulated slider controls displayed on a computer monitor, each slider control for selecting a separate frequency band of the multi-band equalizer. This implementation is described presently with reference to FIG. **3**. It is understood

that any user interface, and any structure of the user interface, providing a structure to input a user prescribed gain setting/gain change is within the scope of the present invention. In implementations, exemplary user interfaces may illustratively include a mechanical slide control, a mechanical rotating knob, a simulated slide control displayed on a monitor as illustratively portrayed in FIG. **3**, a simulated rotating knob control displayed on a monitor, and a window(s) displayed on a monitor to input a user selected gain/change by a menu selection structure or by a character input via a keyboard like device.

The computer interface application **150** is implemented as a routine stored on a media that in operation is executed by the computer. The computer interface application **150** is configured to drive the computer interface **140**, to receive from the computer interface **140** the user provided equalizer gain or change in gain settings, and to provide the user selected gain settings, or change in gain settings, to the gain calculator application **130**.

The gain calculator application **130** is implemented as a routine stored on a media that in operation is executed by the computer. The gain calculator application **130** calculates (or computes) the computer user interface system **110** provided gain settings/changes to adjust the settings so that the audio signal will not be distorted. In one implementation, the gain calculator application **130**, in response to a user selected increase in one band of the equalizer, calculates a lower gain in each of the other bands of the equalizer, so that the equalizer audio output signal is not distorted. In one implementation, the gain calculator application **130**, in response to the user selected increase in one band of the equalizer, calculates a lower gain in each of the other bands of the equalizer so that the overall power (or amplitude) of the audio signal does not increase, or increases a fraction of what

would otherwise be the gain in power. The gain calculator application **130** provides these calculated values to the equalizer application **120**. The gain calculator application **130** is further described with reference to FIGs. **5** and **6**. In one implementation, the gain calculator application **130** provides the prescribed gains to the equalizer application **120** via an application program interface (API).

The equalizer application **120** is implemented as a routine stored on a media that in operation is executed by the computer. The equalizer application **120** comprises an equalizer filter application **160**. The equalizer filter application **160** is implemented as a routine stored on a media that in operation is executed by the computer. The equalizer filter application **160** comprises a digital band pass filter implemented by a programmed computer. Illustrative implementations of a digital filter include an infinite impulse response filter, such as a Butterworth filter, a Bessel filter, and a Chebyshev filter; and a finite-impulse response filter such as a raised cosine filter. Each filter of the equalizer filter application **160** may be embodied as a separate routine for each frequency band, or as a common routine for multiple frequency bands. The equalizer application **120** receives the gain calculator application **130** provided band pass filter gain setting/change, and provides these settings to the equalizer filter application **160**. In one implementation, the equalizer application is configured to generate filter coefficients as prescribed by a particular filter type, to operate each filter of the filter application **160**. Each filter of the equalizer filter application **160** is applied to the input audio signal to produce an equalized output audio signal. The filters **355**$_i$ are applied to an input audio output signal **370** to produce the equalized audio signal **375**. In one implementation, the filter coefficients are provided by the gain calculator application **130** rather than being generated by the equalizer application

120. In one implementation, the equalizer application **120** is a plug-in. In one implementation, the equalizer filter application **160** is a plug-in. In one implementation, the computer interface application **150** provides the prescribed gains to the equalizer application **120** via an API. The equalizer filter application **160** is further described with reference to FIG. **3**.

FIG. **2** shows some components of an exemplary audio system implemented on a computer system **200**. The computer system **200** includes an at least one processor **210** and a coupled memory **220**. In one implementation, the processor **210** is a general purpose processor. In one implementation, the processor **210** is a processor is a processor of a general purpose computer (PC), or a digital audio player such as a Windows Media® (a trademark of the Microsoft Corporation) Audio (WMA) player or an MP3 audio player. The computer system **200** is configured to process audio data from illustratively an input device such as a CD player coupled to the computer system **200**, the memory **220**, or a network interface for downloading data form a network (not shown). The memory **220** stores the instructions of the computer interface application **150**, the gain calculator application **130**, the equalizer application **120**, and the equalizer filter application **160**, each described with reference to FIG. **1**. The computer interface application **150**, the gain calculator application **130**, the equalizer application **120**, and the equalizer filter application **160** comprise instructions to be executed by the processor **210** in operation of the audio system. The computer system **200** further includes a coupled computer user interface **140** as illustratively described with reference to FIG. **1**. The computer user interface **140** is a device for a user to select equalizer gain settings/changes, and to provide those gain settings/changes to the computer interface application **150** as described with reference to FIG. **1**.

The computer system **200** further includes a selection/input device **230** for a user to input data and/or select data from the computer user interface **140**. Illustrative selection/input devices **230** include a keyboard, a mouse, and/or a touchpad with selection buttons.

FIG. **3** shows one implementation of the audio system **100**. The audio system **100** comprises an illustrative computer user interface **140**. The computer user interface **140** is a computer monitor configured to display a structure **310** for a user to select equalizer gain settings/changes. The structure **310** illustratively comprises exemplary band controls $\mathbf{330_i}$, portrayed as 5 separate band controls $\mathbf{330_1}$, $\mathbf{330_3}$, $\mathbf{330_3}$, $\mathbf{330_4}$, and $\mathbf{330_5}$. Each band control $\mathbf{330_i}$ is illustratively portrayed as a simulated slider control $\mathbf{340_i}$ for an exemplary frequency band $\mathbf{345_i}$.

As portrayed, the band adjustment $\mathbf{330_1}$ comprises a slider control $\mathbf{340_1}$ for the exemplary frequency band 31 HZ $\mathbf{345_1}$. Similarly, the band adjustment $\mathbf{330_2}$ comprises a slider control $\mathbf{340_2}$ for the exemplary frequency band 125 HZ $\mathbf{345_2}$, the band adjustment $\mathbf{330_3}$ comprises a slider control $\mathbf{340_3}$ for the exemplary frequency band 500 HZ $\mathbf{345_3}$, the band adjustment $\mathbf{330_4}$ comprises a slider control $\mathbf{340_4}$ for the exemplary frequency band 4 KHZ $\mathbf{345_4}$, and the band adjustment $\mathbf{330_5}$ comprises a slider control $\mathbf{340_5}$ for the exemplary frequency band 16 KHZ $\mathbf{345_5}$. It is understood that any user interface **100**, and any structure **120** of the user interface **100**, that provides a structure to input a user prescribed gain setting/gain change is within the scope of the present invention.

The output of the computer user interface **140** is provided to the operationally coupled computer interface application **150** which in turn provides the user selected gain settings/changes to the operationally coupled gain calculator application **130**. The gain calculator application **130** calculates (or computes)

computer interface application **150** provided gains, and provides in one implementation the gain for each band **345**$_i$ to the operationally coupled equalizer application **120**, for a band pass filter **355**$_i$ of the equalizer filter application **160**. Each band **345i** is therefore operationally coupled to a filter **355**$_i$ through the gain calculator application **130**. In one implementation, as described with reference to FIG. **1**, the gain calculator application provides the filter coefficients for each band **345**$_i$ to the equalizer application **120**, for a band pass filter **355**$_i$. The filters **355**$_i$ are applied to an input audio output signal **370** to produce the equalized audio output signal **375**. In one implementation, the equalizer **120** is a plug-in. In one implementation, the equalizer band filter **160** is a plug-in.

FIG. **4** shows one implementation of an audio system **400** in which the gain calculator application **130** is implemented by an algorithm described presently. The illustrative audio system **400** has the user interface **140**, including the display structure **310**, as described with reference to FIGs. **1** and **3**. If a user raises the gain in one band of a multi-band equalizer having "B" bands, the gain calculator application **130** is configured to respond to the raised gain in the one band, by algorithmically lowering the gain in each of the other B-1 bands such that the power of the equalized audio output signal **375** is substantially the same as the power of the input audio signal **370**. To the user, the band that was raised takes on the same relative prominence in the audio as with a normal equalizer, but the audio is not louder (more powerful) overall. Illustratively, the display structure **310** portrays the result of a user raising the gain of the 31 HZ band by "N" (such as "N" decibels) as a result of translating the slider control **340**$_1$ upward to the "plus N" decibel position. The gain calculator application **130** is configured according to its program instructions to algorithmically adjust the gain of the illustrative

other B-1 bands of the equalizer **120** by subtracting, for each of these other B-1 bands, a gain of substantially N/(B-1) $\mathbf{431_2}$ $\mathbf{431_3}$ $\mathbf{431_4}$ $\mathbf{431_5}$ from what would otherwise be the gain. By reducing the gain in each of the other "B"-1 bands by N/(B-1), the power of the equalized audio output signal **375** is substantially the same as the power of the input audio signal **370** while maintaining the selected gain increase in the selected 31 HZ band. The calculated gains of the gain calculator application **130** are provided to the equalizer application **120** and equalizer filter application **160**, as described with reference to FIGs. **1** and **3**. In one implementation, the gain of the other B-1 bands is reduced geometrically. In one implementation, the gain of at least one of the other B-1 bands is not calculated. In one implementation, the gains of each of the bands being calculated are not adjusted equally.

FIG. **5** shows one implementation of an audio system **500** in which the gain calculator application **130** is implemented by an algorithm described presently. The illustrative audio system **500** has the user interface **140**, including the display structure **310**, as described with reference to FIGs. **1** and **3**. If a user raises the selected gain in one band of a multi-band equalizer having "B" bands, the gain calculator application **130** is configured to respond to the raised gain in this one band by algorithmically lowering the gain in each of the other B-1 bands, such that the power of the equalized audio output signal **375** is raised. Rather than maintaining the loudness of the audio (as described above with reference to FIG. **4**), some power is added to the equalized audio output signal **375** to provide to the user with a sensation of increased power in the equalized audio output signal **375** upon the positive gain adjustment in one band. This adding of power in the equalized audio output signal **375** may introduce some distortion to the equalized

audio output signal **375**, but less distortion than if the gain were not reduced in the other B-1 bands. The inventor understands that raising the gain by approximately 20% in each of the other bands does not unduly distort the equalized audio output signal **375**, while it does provide a listener with an adequate sensation of a raised overall audio level.

Illustratively, the display structure **310** portrays the result of a user raising the gain of the 31 HZ band by "N" (such as "N" decibels) as a result of translating the slider control $\mathbf{340_1}$ upward to the "plus N" position. The gain calculator application **130** is configured according to its program instructions to algorithmically adjust the gain of the illustrative other B-1 bands of the equalizer **120** by subtracting, for each of the other B-1 bands, a gain of substantially (X*N)/(B-1) $\mathbf{531_2}$ $\mathbf{531_3}$ $\mathbf{531_4}$ $\mathbf{531_5}$ from what would otherwise be the gain (where X represents the fraction of N/(B-1) that is being subtracted from the gain, and "*" represents a multiplication operation). By reducing the gain in each of the other B-1 bands by a fraction "X" of N/(B-1), the power of the equalized audio output signal **375** is reduced in each band, but increased overall. The inventor understands that an "X" valued at 80% results in an adequately perceptible increase in power while at the same time helping to reduce overall distortion and not unduly distorting the equalized audio output signal **375**. The calculated gains of the gain calculator application **130** are provided to the equalizer application **120** and equalizer filter application **160** as described with reference to FIGs. **1** and **3**. In one implementation, the gain of the other B-1 bands is reduced geometrically. In one implementation, the gain of at least one of the other B-1 bands is not calculated. In one implementation, the gains of each of the bands being calculated are not adjusted equally.

FIG. **6** shows an exemplary method **600** to determine the gain in each of the bands of a multi-band equalizer. In one implementation, at least one computer includes stored instructions that when executed by the computer(s) (or processor(s) of the computer(s)), cause the computer(s) to execute the method **600**. Referring now to FIG. **6**, in response to a user raising a gain in one band of a multi-band equalizer, operation **610** determines a change in gain (or power or volume represented by the equalizer audio output signal) in the raised band. Operation **620** calculates (or computes) the gain of the bands of the equalizer that were not raised so as to lower the overall power (or volume) represented by the output audio signal of the equalizer.

In one illustrative implementation of operation **620**, the gain (or power or volume) of each of the bands that was not raised are calculated to be approximately uniformly lower such that the absolute value of the total gain (or power or volume represented by the equalizer audio output signal) of the bands that were not raised are lowered by the absolute value of the gain (or power or volume represented by the equalizer audio output signal) of the band that was raised. This implementation is expressed in mathematical notation, by calculating the gain (or power or volume) of each band that was not raised by subtracting N/(B-1) from each of the other bands, where "N" represents the amount of gain (or power or volume) that the one band is raised, and "B" represents the total number of bands in the equalizer.

In one illustrative implementation of operation **620**, the gain (or power or volume) of each of the bands that was not adjusted are calculated to be approximately uniformly lower such that the absolute value of the total gain of the bands that were not raised are lowered by a fraction of the absolute value of the

gain (or power or volume represented by the equalizer audio output signal) of the band that was raised. This implementation is expressed in mathematical notation, by calculating the gain (or power or volume) of each band that was not raised by subtracting (X*N)/(B-1) from each of the other bands, where "N" represents the amount of gain (or power or volume) that the one band is raised, "X" represents the fraction of the absolute value of the gain (or power or volume) of the band that was raised, "*" represents the multiplication function, and "B" represents the total number of bands in the equalizer. The inventor understands that an "X" valued at 80% results in an adequately perceptible increase in power while at the same time limiting helping to reduce overall distortion and not unduly distorting the equalized audio output signal. In one illustrative implementation, the gain of the other B-1 bands is reduced geometrically. In one illustrative implementation, the gain of at least one of the other B-1 bands is not calculated. In one illustrative implementation, the gains of each of the bands being calculated are not adjusted equally.

Operation **630** provides the calculated gain of the other bands to an equalizer. Operation **640** adjusts the gain of the equalizer in each band according to the raised gain in the one band, and the calculated gain in the other bands.

Although the invention has been described in language specific to structural features and/or methodological acts, it is to be understood that the invention defined in the appended claims is not necessarily limited to the specific features or acts described. Rather, the specific features and acts are disclosed as exemplary forms of implementing the claimed invention.